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Bagayatkar

(54) **WASTE HEAT RECOVERY HYBRID POWER DRIVE**

(71) Applicant: **Cummins, Inc.**, Columbus, IN (US)

(72) Inventor: **Nimish Bagayatkar**, Carmel, IN (US)

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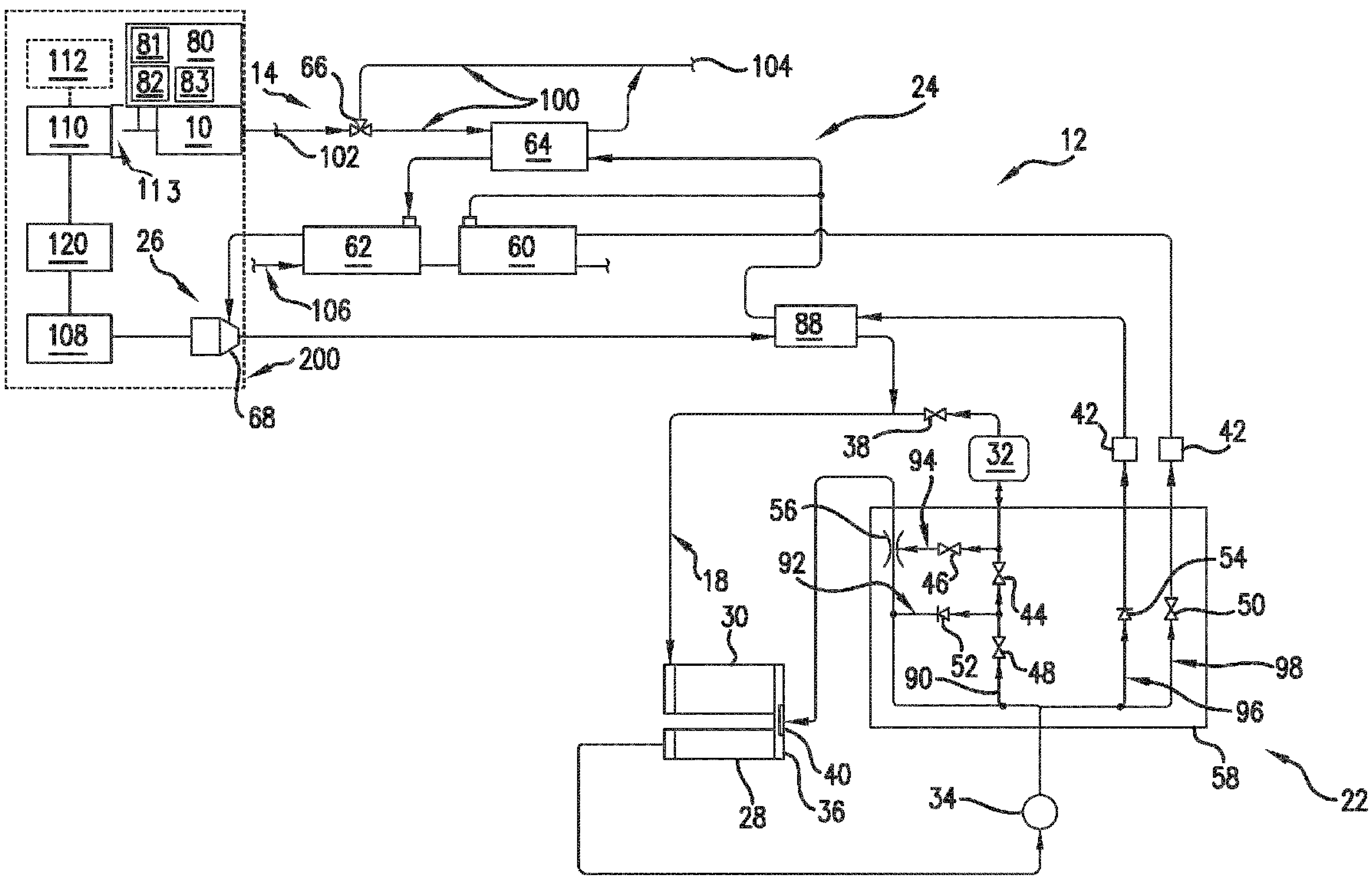
(57) **ABSTRACT**

A system includes an internal combustion engine; a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; a gear box operatively coupled to an output of the energy conversion system; and an alternator operatively coupled to the gear box and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.



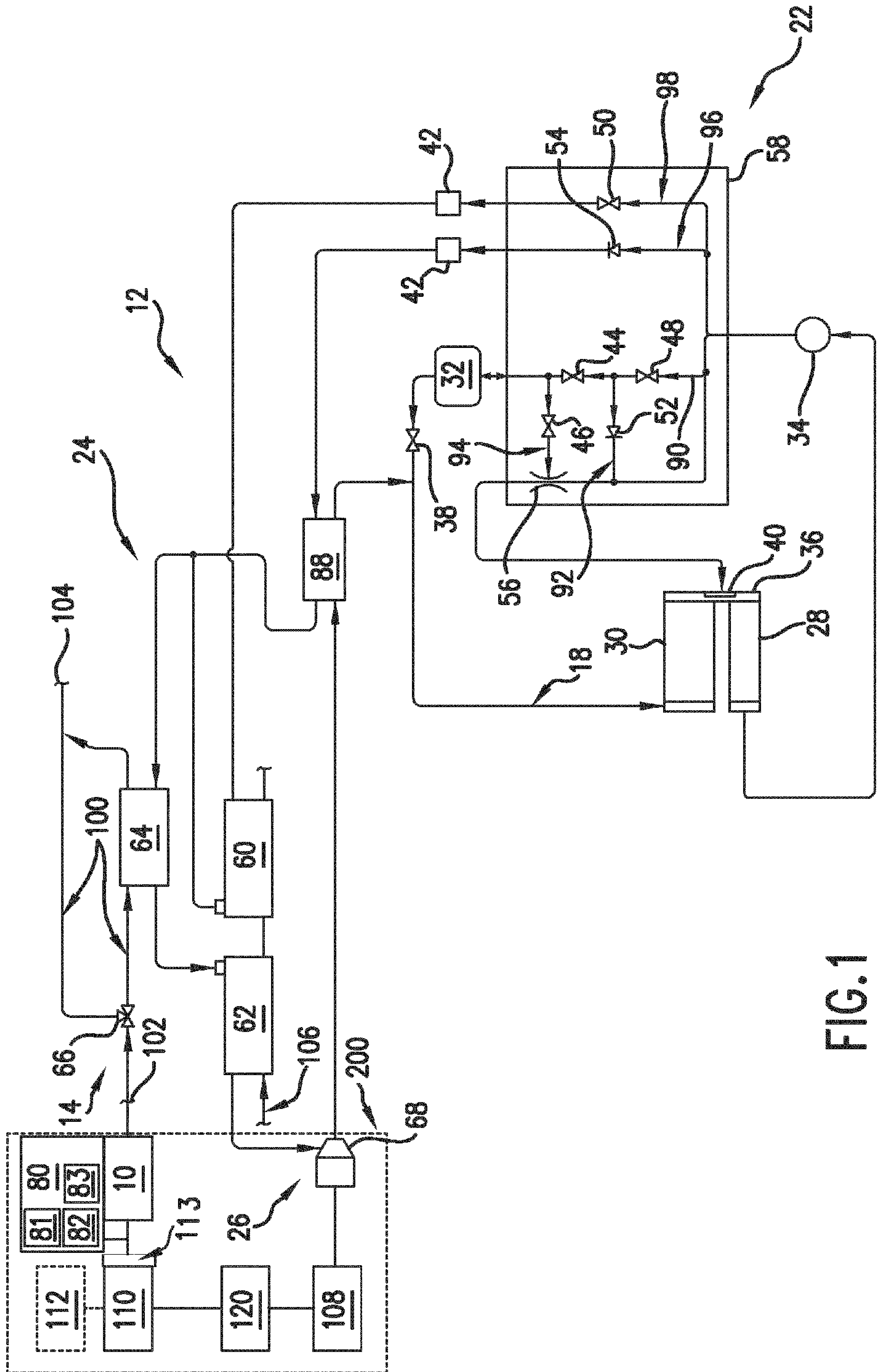

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FIG. 1

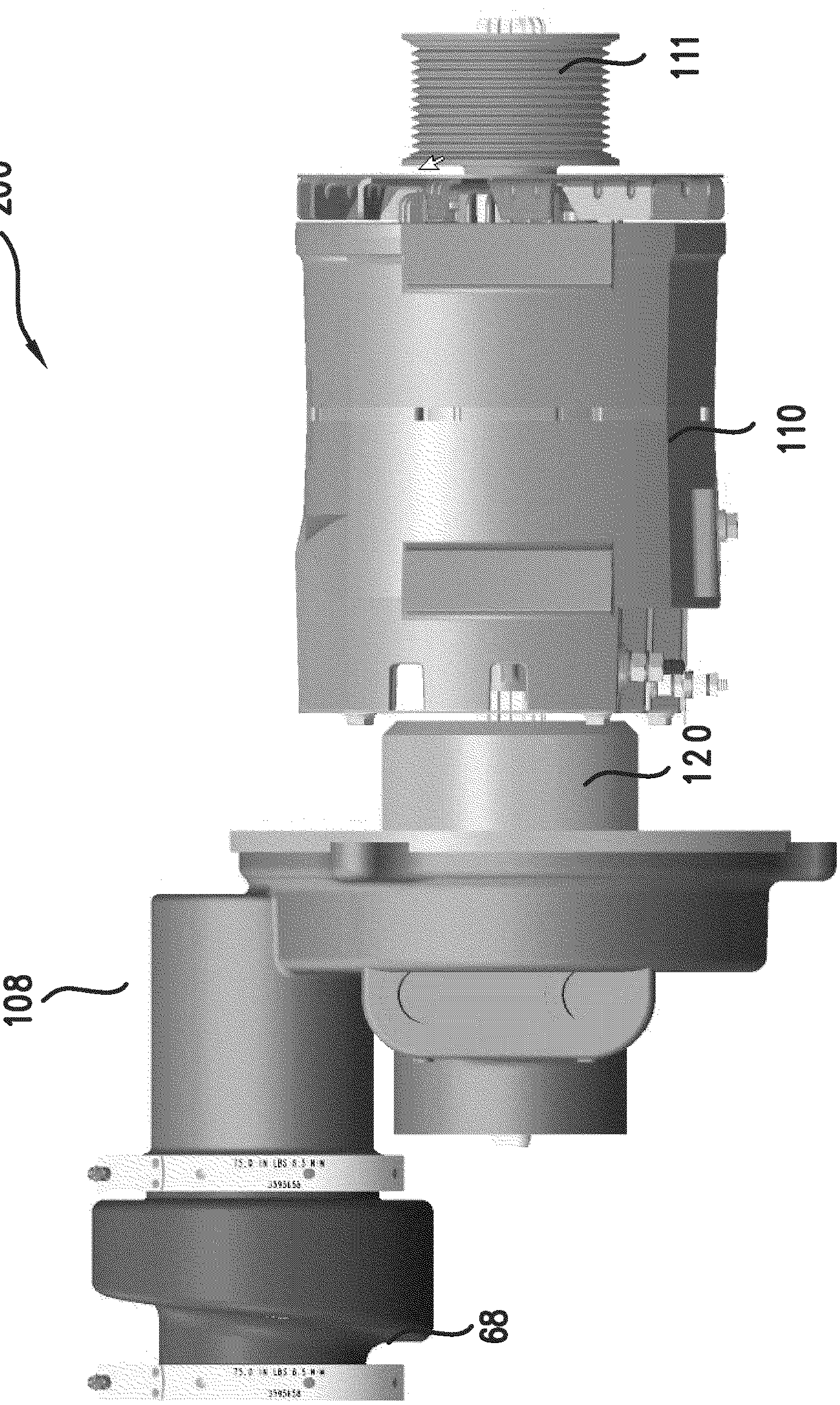

FIG.2

WASTE HEAT RECOVERY HYBRID POWER DRIVE

TECHNICAL FIELD

[0001] This disclosure relates to Waste Heat Recovery (WHR) systems. More particularly, the disclosure relates to WHR systems used with hybrid vehicles.

BACKGROUND

[0002] A waste heat recovery (WHR) system recovers heat energy from an internal combustion engine that would otherwise be lost. The more waste heat energy extracted from an internal combustion engine by a WHR system, the greater the potential efficiency of the engine. In other words, rather than the extracted heat being lost, the extracted heat energy may be repurposed to, e.g., supplement the power output from the internal combustion engine thereby increasing the efficiency of the system. However, the WHR system requires energy to operate, such as the energy required to operate a feedpump to pump a working fluid through the WHR system. The energy required to operate the WHR system represents a loss to the efficiency gained from the WHR system.

SUMMARY

[0003] One embodiment relates to a vehicle. The vehicle includes an internal combustion engine; a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; a gear box operatively coupled to an output of the energy conversion system; and an alternator operatively coupled to the gear box and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system. In one configuration, the vehicle is structured as a hybrid vehicle. In this configuration, the vehicle includes an electric power system structured selectively power the vehicle with or without assistance from the internal combustion engine. In this configuration, the alternator is structured to provide at least a portion of the produced electrical energy to the electrical power system. Advantageously, the provided electrical energy stems from recovered waste heat energy, which increases the relative efficiency of the vehicle.

[0004] Another embodiment relates to a system. The system includes an internal combustion engine; a waste heat recovery system having a working fluid circuit, a fluid management system positioned along the working fluid circuit that utilizes a working fluid, a heat exchange system positioned along the working fluid circuit, and a feedpump positioned along the working fluid circuit and structured to move the working fluid through the working fluid circuit; an energy conversion system positioned along the working fluid circuit downstream from the heat exchange system and upstream from the fluid management system, wherein the energy conversion system is structured to generate power from heat energy extracted from the engine via the waste heat recovery system; a gear box operatively coupled to an output of the energy conversion system; a coupling structured to selectively receive the output of the energy conversion system; and an alternator operatively coupled to the coupling and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

[0005] Still another embodiment relates to a method. The method includes providing an internal combustion engine; providing a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; and providing an alternator operatively coupled to the energy conversion system and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

[0006] Advantages and features of the embodiments of this disclosure will become more apparent from the following detailed description of exemplary embodiments when viewed in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a schematic of an internal combustion engine with a WHR system, according to an example embodiment.

[0008] FIG. **2** is a schematic diagram of an alternator, a coupling, a gearbox, and an expander used with WHR and engine system of FIG. **1**, according to an example embodiment.

DETAILED DESCRIPTION

[0009] Referring to the Figures generally, various embodiments disclosed herein relate to systems and methods of outputting two forms of energy from a WHR system. According to the present disclosure, a system includes an engine, WHR system, an alternator, and a coupling to connect or couple the WHR system to the alternator. The WHR system extracts power from the WHR working fluid and outputs it in the form of a torque on a rotating shaft. Via the coupling, the torque on the rotating shaft is transferred to the alternator. The alternator may be part of a front end accessory drive (FEAD) system, such that the alternator powers front end accessories such as water pumps, power steering pumps, compressors, etc. The alternator may also receive power from the crankshaft of the engine. According to the present disclosure, the alternator consumes or utilizes some of the power extracted by the WHR system to generate electrical energy while the remainder or most of the remainder of the extracted energy is absorbed by the engine via the FEAD system through the crankshaft (i.e., the dual or two forms of energy).

[0010] Advantageously, by coupling the WHR system with the alternator, otherwise lost heat energy may be used to generate electrical energy. According to one embodiment, the present disclosure is implemented with a hybrid vehicle (vehicles powered by two different types of energy, such as electrical energy from an electrical motor and chemical energy via combustion in an internal combustion engine). Beneficially, relatively more electrical energy may be generated to power the electrical motor of the hybrid vehicle than in conventional hybrid vehicles via the coupling to the alternator. This provides a technical advantage over current hybrid vehicle technology, which may be appealing to consumers. These and other features of the present disclosure are more fully described herein below.

[0011] Referring now to FIG. **1**, an engine **10** and waste heat recovery (WHR) system is shown, according to one embodiment. It should be noted that the engine **10** and WHR system **12** shown in FIG. **1** is an example configuration. Other configurations may include or exclude other and different components. For example, in some embodiments, the exhaust gas recirculation (EGR) system **100** may be excluded from the system. Similarly, in other embodiments, the exhaust system may include one or more aftertreatment components, such as a diesel oxidation catalyst, a diesel particulate filter, and a selective catalytic reduction catalyst. However, the principles and disclosure described herein is still applicable to these variations. Therefore, all of these variations are intended to fall within the spirit and scope of the present disclosure.

[0012] In the example depicted in FIG. **1** (and FIG. **2**), all of the components depicted are embodied in a vehicle. The vehicle **100** may be an on-road or an off-road vehicle including, but not limited to, line-haul trucks, mid-range trucks (e.g., pick-up truck), sedans, coupes, compacts, sport utility vehicles, and any other type of vehicle that utilizes cruise control systems.

[0013] As shown, the vehicle is structured as a hybrid vehicle (e.g., a vehicle that selectively uses two different energy sources to propel the vehicle). The vehicle includes an engine **10** structured as an internal combustion engine. The internal combustion engine may include a spark-ignition engine and a compression ignition engine. Accordingly, the engine **10** may be fueled by any fuel, such as gasoline, diesel, and ethanol. In operation, the engine **10** receives a chemical energy input (e.g., a fuel such as gasoline, diesel, etc.) and combusts the fuel to generate mechanical energy, in the form of a rotating crankshaft. A transmission (not shown) receives the rotating crankshaft and manipulates the speed of the crankshaft to affect a desired drive shaft speed. The rotating drive shaft is received by a differential, which provides the rotation energy of the drive shaft to the final drive (e.g., wheels, etc.). The final drive then propels or moves the vehicle.

[0014] The vehicle also includes an electric power system **80**. The electric power system **80** is structured to selectively power or propel the vehicle in combination with or separate from the engine **10**. The electric power system **80** includes one or more energy storage devices **81** (e.g., batteries) and an electric motor **82**. The electric motor **82** receives power from the one or more energy storage devices **81** to selectively propel the vehicle. The components shown as part of the electric power system **80** are not meant to be limiting as the electric power system may include additional features with additional functionality. For example, components relating to a regenerative braking system may also be included in the electric power system. Accordingly, the electric power system **80** is meant to be broadly interpreted.

[0015] According to one embodiment, the WHR system **12** described herein is a Rankine cycle waste heat recovery system, or an organic Rankine cycle if the working fluid is an organic high molecular mass fluid with a liquid-vapor phase change that is lower than the water-steam phase change. Examples of Rankine cycle working fluids, organic and inorganic, include Genetron® R-245fa from Honeywell, Therminol®, Dowtherm J™ from Dow Chemical Co., Fluorinol® from American Nickeloid, toluene, dodecane, isododecane, methylundecane, neopentane, neopentane, octane, water/methanol mixtures, or steam.

[0016] As shown, the WHR system **12** includes a WHR circuit **18**, along which are positioned a fluid management system **20**, a fluid control portion **22**, a heat exchange system **24**, and an energy conversion system **26**. The fluid management system **20** provides storage or containment, and cooling for a working fluid of the WHR system **12**. The fluid control portion **22** regulates the flow of the working fluid throughout the WHR system **12**. The heat exchange system **24** provides cooling to certain systems of the engine **10** and serves to heat the working fluid to permit the working fluid to drive an energy conversion system **26**, extracting useful work or energy from the waste heat created by the engine **10**.

[0017] The fluid management system **20** includes a sub-cooler **28**, a condenser **30**, a receiver **32**, and a feedpump **34**. The receiver **32** serves primarily as a reservoir for the WHR system **12**. The condenser **30** serves to convert gaseous working fluid to liquid working fluid. The sub-cooler **28** provides cooling to the liquid working fluid. The condenser **30** may be integral with sub-cooler **28**, may connect to sub-cooler **28** by way of WHR circuit **18**, or may be commonly mounted with sub-cooler **28** on a common base **36**, which may include a plurality of fluid flow paths (not shown) to fluidly connect the condenser **30** to the sub-cooler **28**. The receiver **32** may be physically elevated higher than sub-cooler **28**, and may be connected to sub-cooler **28** through fluid control portion **22**. The top of receiver **32** includes a vent that may be opened to the condenser **30** by way of a vent valve **38**. A fluid level sensor **40** is positioned along WHR circuit **18** in a location suitable to determine the level of the liquid working fluid in sub-cooler **28** and condenser **30**. The feedpump **34** is positioned along WHR circuit **18** downstream from sub-cooler **28** and upstream from fluid control portion **22**. The fluid management system **20** may also include one or more filter driers **42** positioned along WHR circuit **18** downstream from fluid control portion **22**. Alternatively, the filter drier **42** may be positioned downstream from the feedpump **34** and upstream from the fluid control portion **22**. All such variations are intended to fall within the spirit and scope of the present disclosure.

[0018] The fluid control portion **22** includes a plurality of valves and an ejector **56** configured to regulate flow as needed throughout WHR system **12**. The valves include actuated on-off valves **44** and **46**, actuated proportional valves **48** and **50**, actuated vent valve **38**, and passive check valves **52** and **54**. In one embodiment, the ejector **56** is a passive device and operates in conjunction with certain valves to draw liquid working fluid from receiver **32**. Many of the valves and ejector **56** may be included within a valve module or body **58**. The function of the various valves and ejector **56** is to control the flow of working fluid in WHR system **12**, which also controls the heat transferred to and from the working fluid flowing through WHR circuit **18**. Though electrically actuated valves **38**, **44**, **46**, **48**, and **50** may be described as on-off or proportional valves, this description is for convenience in the context of the exemplary embodiment. The on-off valves may be proportional valves and the proportional valves may be modulated valves capable of opening and closing rapidly to adjust the amount of working fluid flowing through the valves.

[0019] The heat exchange system **24** includes a recuperator **88**, an EGR boiler **60**, an EGR superheater **62**, an exhaust heat exchanger **64**, and an exhaust control valve **66**. The EGR boiler **60** provides the ability to regulate the temperature of an EGR gas by transferring heat from the EGR gas to the working fluid. It should be understood that the term "EGR boiler" is used for the sake of convenience. EGR boiler **60** may serve more than one function for system, such as cooling the EGR gas and transferring heat from the EGR gas to the working fluid of WHR system **12**. The exhaust heat exchanger **64** permits the controlled transfer of heat from the exhaust of the engine **10** to the working fluid. The amount of heat available to exhaust heat exchanger **64** is determined by exhaust control valve **66**. The EGR superheater **62** transfers additional heat energy from the EGR gas to the working fluid, which is in a gaseous state when it enters EGR superheater **62**. The EGR superheater **62** is positioned along WHR circuit **18** downstream from exhaust heat exchanger **64** and upstream from condenser **30**.

[0020] The exhaust heat exchanger **64** is positioned along the exhaust gas circuit **100**. The exhaust gas circuit **100** fluidly connects an upstream aftertreatment system **102** to exhaust heat exchanger **64**. The exhaust control valve **66** is positioned between aftertreatment system **102** and exhaust heat exchanger **64**. Both the exhaust control valve **66** and the exhaust heat exchanger **64** are fluidly connected on their downstream sides by exhaust gas circuit **100** to an atmospheric vent **104**, which may be a tailpipe, exhaust pipe, exhaust stack, or the like.

[0021] The EGR superheater **62** and EGR boiler **60** are connected to a portion of an EGR circuit **106**. EGR gas flows along EGR circuit **106** into the EGR superheater **62** and then downstream from EGR superheater **62** into the EGR boiler **60**. From the EGR boiler **60**, the EGR gas flows downstream along EGR circuit **106**. The EGR superheater **62** and the EGR boiler **60** serve as heat exchangers for the EGR circuit **106**, providing a cooling function for the EGR gas flowing through EGR superheater **62** and EGR boiler **60**. The EGR superheater **62** and the EGR boiler **60** also serve as heat exchangers for the WHR circuit **18**, raising the temperature of working fluid flowing through EGR boiler **60** and through the EGR superheater **62**.

[0022] As shown, the fluid control portion **22** may include a plurality of parallel flow path portions formed along the WHR circuit **18** that connect the feedpump **34** to various elements of the WHR system **12**. A first flow path portion **90** fluidly connects the downstream side of the feedpump **34** to the receiver **32**. Positioned along the first flow path portion **90** between the feedpump **34** and the receiver **32** is a proportional valve **48**, which is downstream from the feedpump **34** and upstream from the receiver **32**. Positioned along the first flow path portion **90** between the proportional valve **48** and the receiver **32** is an on-off valve **44**. Though not part of the first flow path portion **90**, a vent valve **38** is positioned along the WHR circuit **18** between the receiver **32** and the condenser **30**. The purpose of the vent valve **38** is to permit vapor to move into and out from the receiver **32** as liquid working fluid is moved out from and into the receiver **32** along the first flow path portion **90**.

[0023] A second flow path portion **92** extends from a location along the first flow path portion **90** between the proportional valve **48** and the on-off valve **44** to fluidly connect to the sub-cooler **28** and the condenser **30**. The passive check valve **52** is positioned along the second flow path portion **92**, and the ejector **56** is positioned along the second flow path portion **92** between the passive check valve **52** and the sub-cooler **28** and/or the condenser **30**, downstream from the passive check valve **52** and upstream from the sub-cooler **28** and/or the condenser **30**. The first flow path portion **90** is also connected to the second flow path portion **92** by a connection path portion **94**, which extends from a location between the on-off valve **44** and the receiver **32** to the ejector **56**. The on-off valve **46** is positioned along connection path portion **94**.

[0024] A third flow path portion **96**, which is parallel to the first flow path portion **90** and to the second flow path portion **92**, fluidly connects the feedpump **34** to the recuperator **88**. The passive check valve **54** is positioned along the third flow path portion **96**, between the feedpump **34** and the recuperator **88**. The recuperator **88** is connected on a downstream side to the exhaust heat exchanger **64**. The filter drier **42** may be positioned along the WHR circuit **18** between the recuperator **88** and the passive check valve **54**. The recuperator **88** is also positioned along the WHR circuit **18** between the energy conversion system **26** and the condenser **30**, downstream from the energy conversion system **26** and upstream from the condenser **30**.

[0025] A fourth flow path portion **98**, which is parallel to the first flow path **90**, second flow path portion **92**, and third flow path portion **96**, fluidly connects the feedpump **34** to the EGR boiler **60**. The exhaust heat exchanger **64** is positioned downstream from the EGR boiler **60** and the recuperator **88**. Thus, any working fluid flow along third flow path portion **96** and working fluid flow along fourth flow path portion **98** converges prior to entry into the exhaust heat exchanger **64**. The proportional valve **50** is positioned along fourth flow path portion **98** downstream from the feedpump **34** and upstream from the engine heat exchanger **60**. A filter drier **42** may be positioned along the WHR circuit **18** downstream from the proportional valve **50** and upstream from the EGR boiler **60**.

[0026] With the components of the WHR system **12** described above, operation of the WHR system **12** may be described as follows. The sub-cooler **28** stores the liquid working fluid. The feedpump **34** pulls or draws liquid working fluid from the sub-cooler **28**. The feedpump **34** then forces liquid working fluid downstream to the valve module **58**. In the valve module **58**, the flow of liquid working fluid may be directed to one of four parallel flow path portions. As described above, the first flow path portion **90** connects the feedpump **34** to the receiver **32**, the second flow path portion **92** connects the feedpump **34** to the condenser **30**/sub-cooler **28**, the third flow path portion **96** connects the feedpump **34** to the recuperator **88**, and the fourth flow path portion **98** connects feedpump **34** to EGR boiler **60**. It should be understood that these flow paths are exemplary as more or less flow paths may be used in other systems and arrangements.

[0027] During normal operation of the engine **10**, the proportional valve **48** is at least partially open to permit liquid working fluid to flow into the first flow path portion **90** and then into the second flow path portion **92**, flowing through the passive check valve **54**, which may have a cracking or opening pressure threshold (e.g. five psi), so that liquid working fluid flows through the second flow path portion to the sub-cooler **28**, thus forming a continuous loop of flowing liquid working fluid when check valve **52** opens. If the proportional valve **48** is opened and on/off valve **44** is closed, liquid working fluid flows into the first flow path portion **90** into the second flow path portion **92**, which may be used to prevent the two-phase working fluid flow, i.e., liquid and gas, from reaching the energy conversion system **26**. If the on-off valve **44** is opened when proportional valve **48** is opened, the on-off valve **46** is closed, and the vent valve **38** is opened, the cracking pressure of the check valve **52** causes liquid working fluid to flow upwardly along first flow path portion **90** to the receiver **32**. The flow of fluid into the receiver **32** causes the level of liquid working fluid in the receiver **32** to increase, and causes the level of liquid working fluid in the sub-cooler **28** and/or the condenser **30** to decrease. Thus, in this valve configuration the feedpump **34** may be connected simultaneously to the sub-cooler **28** and to the receiver **32**.

[0028] If the on-off valve **46** is open, the on-off valve **44** is closed, and the vent valve **38** is open while liquid working fluid flows from the feedpump **34** along first flow path portion **90** into the second flow path portion **92** and then into sub-cooler **28** and/or condenser **30**, then the receiver **32** is connected to the sub-cooler **28** and/or the condenser **30** along a portion of the WHR circuit **18** that is parallel to the portion of the WHR circuit **18** that connects the feed pump **34** to the sub-cooler **28** and/or the condenser **30**. In this valve configuration, liquid working fluid will be drawn from receiver **32**, flowing through a portion of the first flow path portion **90** through the on-off valve **46**, which is positioned along the connection path portion **94**, into the ejector **56**. The liquid working fluid then flows downstream from the ejector **56** to the sub-cooler **28** and the condenser **30**, increasing the level of liquid working fluid in the sub-cooler **28** or in the condenser **30**. The level of liquid working fluid may vary sufficiently that the condenser **30** may contain some liquid working fluid. The increase in the level of the liquid working fluid in sub-cooler **28** increases sub-cooling, adjusting the saturation temperature of the liquid working fluid. The vent valve **38** is normally open during operation of engine **10**, which permits vapor to flow to and from the top portion of receiver **32** to and from a top portion of condenser **30**, permitting the level of liquid working fluid in receiver **32** to increase or decrease. Once the level of liquid working fluid has been increased in sub-cooler **28** and/or condenser **30** a desirable amount, the on-off valve **46** is closed, stopping flow from receiver **32** through connection path portion **94**.

[0029] Liquid working fluid flows along the third flow path portion **96** based on the opening of proportional valve **50** positioned along the fourth flow path portion **98**. Passive check valve **54** creates a backpressure along the upstream portion of third flow path portion **96**, which biases the flow of liquid working fluid along fourth flow path portion **98**. By partially closing the proportional valve **50**, the backpressure along the upstream portion of the fourth flow path portion **98** increases, until passive check valve **54** cracks or opens under the increased backpressure from the proportional valve **50**. Relatively small amounts of liquid working fluid normally flow through the first flow path portion **90** and the second flow path portion **92**, so most of the liquid working fluid provided to the WHR circuit **18** by the feedpump **34** flows through the third flow path portion **96** and the fourth flow path portion **98**. Flow of working fluid through the third flow path portion **96** and the fourth flow path portion **98** converges upstream from the exhaust heat exchanger **64**.

[0030] Cooling of exhaust gas in the exhaust heat exchanger **64** is an optional function that may be reduced in favor of cooling of EGR gas in the EGR boiler **60**. Thus, the configuration of these components is advantageous in providing priority cooling to the EGR gas. Additional heat may then be added to the working fluid as needed in the exhaust heat exchanger **64** and the EGR superheater **62** by the WHR system **12** to obtain optimal superheating of the working fluid. The working fluid, which is in a gaseous state because of heat transfer from the above-described heat exchangers, flows from exhaust gas heat exchanger **64** into the EGR superheater **62**, where additional heat energy is added to the gaseous working fluid. The superheated gaseous working fluid flows from the EGR superheater **62** into energy conversion device **68**.

[0031] The flow of the working fluid through the WHR system **12** extracts heat energy. As described herein, the heat energy may be used by the energy conversion system **26** to transfer energy to another system or device.

[0032] It should be understood that in certain embodiments, the WHR system **12** further includes a controller structured to perform certain operations to control or regulate the flow of the working fluid through the system **12**. In certain embodiments, the controller forms a portion of a processing subsystem including one or more computing devices having memory, processing, and communication hardware. The controller may be a single device or a distributed device, and the functions of the controller may be performed by hardware and/or as computer instructions on a non-transient computer readable storage medium. In certain embodiments, the controller includes one or more modules structured to functionally execute the operations of the controller. Modules may be implemented in hardware and/or as computer instructions on a non-transient computer readable storage medium, and modules may be distributed across various hardware or computer based components. To facilitate the accurate control by the controller, the WHR system **12** may include one or more sensors strategically positioned and communicatively coupled to the controller. The sensors may include, but are not limited to, temperature sensors, pressure sensors, flow sensors, etc. Accordingly, example and non-limiting module implementation elements include sensors, like described above, providing any value used by the controller, sensors providing any value that is a precursor to a value determined, datalink and/or network hardware including communication chips, oscillating crystals, communication links, cables, twisted pair wiring, coaxial wiring, shielded wiring, transmitters, receivers, and/or transceivers, logic circuits, hard-wired logic circuits, reconfigurable logic circuits in a particular non-transient state configured according to the module specification, any actuator including at least an electrical, hydraulic, or pneumatic actuator, a solenoid, an op-amp, analog control elements (springs, filters, integrators, adders, dividers, gain elements), and/or digital control elements.

[0033] Referring now to FIG. **1** in connection with FIG. **2**, description of the components located in section **200** is now explained. As mentioned above, the WHR system **12** is operatively coupled to an energy conversion system **26**. The energy conversion system **26** is structured to produce additional work or transfer energy to another device or system.

The energy conversion system **26** is shown to include an energy conversion device **68**. The energy conversion system **26** may be a turbine, piston, scroll, screw, or other type of expander device that moves, e.g., rotates, as a result of expanding working fluid vapor to provide additional work. Alternatively, energy conversion system **26** can be used to transfer energy from one system to another system (e.g., to transfer heat energy from WHR system **12** to a fluid for a heating system). The energy conversion device **68** is positioned along the WHR circuit **18** and is downstream from the EGR superheater **62** and upstream from the condenser **30** in this embodiment.

[0034] According to the present disclosure, the energy conversion device **68** is operatively coupled to an energy transfer device, shown as gear box **108**. In this embodiment, the energy conversion device **68** is structured as an expander (FIG. **2**). The expander receives and expands the working fluid from the WHR system **12** to generate power in the form of a rotating shaft. The rotating shaft is received by the gear box **108**. The gear box **108** is structured to include one or more gear trains corresponding to one or more gear ratios (expander shaft input-to-gear box output). The gear box **108** is structured to reduce a speed of rotation of the shaft of the expander **68** to an operating shaft speed of the shaft of the alternator **110**. For example, the alternator **110** may have a prescribed operating shaft speed. The gear box **108** is structured to match or substantially match the expander shaft speed with that operating speed of the alternator shaft. Therefore, in some embodiments, the gear box **108** may act like an overdrive and increase the expander shaft speed while in other embodiments the gear box **108** may reduce the expander shaft speed to align or substantially align with the intended operating speed of the alternator **110** shaft. In this regard, the system of the present disclosure may maintain or nearly maintain efficient operation of the alternator **110**. According to another embodiment, the alternator **110** may utilize electric load balancing (e.g., altering the torque applied to the shaft of the alternator **110** by selectively adjusting the current in the windings) to control a speed of the alternator shaft to enhance speed matching between the expander **68** and the alternator **110**. According to an alternate embodiment, the gear box **108** may be removed from the system, such that the alternator **110**, via electric load balancing, synchronizes or substantially synchronizes the speed of the expander shaft to the alternator shaft.

[0035] The alternator **110** is structured as an on-engine **10** alternator. Accordingly, the alternator **110** may be coupled to a crankshaft of the engine **10**. In other embodiments, the alternator **110** may be replaced with a high capacity alternator for additional electrical power and charging capacity.

[0036] As shown, the alternator **110** is coupled to a coupling **120**. The coupling **120** is operatively coupled to both the alternator **110** and the gear box **108**. In one embodiment, the coupling **120** is structured as a shaft coupling thereby permitting the coupling of a shaft of the alternator **110** to an output shaft of the gear box **108**. In one embodiment, the coupling **120** may selectively engage with at least one of the alternator **110** shaft and the output shaft of the gear box **108**. For example, the coupling **120** may be electromechanically actuated via the controller (described above). In this regard, the coupling **120** may selectively transfer power from the expander **68** to the alternator **110** (or, in certain embodiments, vice versa).

[0037] The alternator **110** is shown to include a front end accessory drive (FEAD) pulley **111**. The FEAD pulley **111** operatively couples (e.g., via one or more belts, such as a serpentine belt and a fan belt, gear chains, etc.) to one or more front end accessories **112** in the vehicle. In this regard, according to another embodiment, the pulley **111** may be structured gear. The gear may be operatively coupled to the engine **10** or integrated into the engine gear train. All such configurations for the pulley **111** are intended to fall within the spirit and scope of the present disclosure. The one or more front end accessories **112** may include, but are not limited to, a water pump, an air conditioning compressor, and a power steering pump. The one or more front end accessories **112** is shown in a dashed line on FIG. **1** to indicate that the alternator **110** may selectively power some of the accessories.

[0038] According to one embodiment, the alternator **110** is coupled to a clutch **113**, where the clutch **113** is coupled to the engine **10**. The clutch **113** may be any type of clutch mechanism that can selectively couple and decouple the alternator **110** to and from the engine **10**. In certain embodiments, the clutch **113** may be actuated via the controller (such as the one described above) to selectively control when the alternator (e.g., a shaft of the alternator) is coupled to the engine **10** and, therefore, driven at least in part by the engine **10**. In this regard, the alternator **110** shaft speed may be controlled via operation of the clutch. This speed control feature may be used independent of or in combination with the electric load balancing of the alternator **110** and operation of the gear box **108**.

[0039] In one embodiment, like shown in FIG. **1**, the alternator **110** is also operatively coupled to the electric power system **80**. The coupling may be via any fashion (such as via a belt, electrical contacts, etc.). In one embodiment, the alternator **110** is electrically coupled to the one or more energy storage devices **81**, such that the alternator **110** may selectively charge the one or more energy storage devices **81**. In another embodiment, the alternator **110** is directly coupled to the electrical motor **82**, such that the alternator **110** directly powers the electrical motor **82**. In still another embodiment, the alternator **110** is coupled to a variable energy dissipation device **83** (e.g., a load bank such as a resistive load bank, etc.) in the vehicle that may be used for a variety of uses in the vehicle, such as braking In other variations, the alternator **110** may be selectively coupled to each of the one or more energy storage devices **81** and the electrical motor **82**. Therefore, in operation, some of the generated power from the extracted waste heat is used to produce electrical energy by the alternator **110** which may be provided to the electric power system. In other embodiments, the produced electrical energy may be provided to other places as well (e.g., one or more electrically-actuated sensors or valves, etc.).

[0040] With reference primarily to FIG. **2**, operation of the section **200** may be described as follows. The WHR system **12** directs working fluid to the energy conversion device, which is embodied as an expander **68** in FIG. **2**. The expander **68** is any device which extracts power from the waste heat recovery working fluid. The expander **68** generates power from the heat energy recovered from the engine **10**. The generated output power is in the form of a torque on a rotating shaft of the expander **68**. The rotating shaft is received by the gear box **108**. The gear box **108** matches the expander rotating shaft speed to the alternator **110** operating shaft speed for a given engine. That is, the alternator shaft speed may vary based on the engine. In other embodiments, and as described above, a clutch such as clutch **113** may couple the alternator to the engine to selectively control the alternator shaft speed to enhance speed matching with the expander. The gear box **108** output shaft is coupled to the alternator shaft by coupling **120**.

[0041] Thus, the alternator **110** may receive power from at least one of the engine **10** (e.g., a crankshaft) and via the WHR system **12** via the coupling **120**, gear box **108**, and energy conversion device **68**. In this regard, the alternator **110** consumes WHR power to generate electrical energy and the remainder is transferred back to the engine via the FEAD through the crankshaft of the engine. Advantageously, this additional amount of energy from the WHR system **12** may be used to power or charge the electrical power system **80** of a hybrid vehicle. This supplemental energy from the WHR system **12** that is routed via the alternator **110** is an additional energy source that may increase the efficiency of the hybrid vehicle of the present disclosure.

[0042] It should be understood that while the systems described herein relate to the use of shaft couplings and gear boxes, Applicants contemplate other energy transfer mechanism (e.g., inductive energy transfer, etc.) that may be used in addition or in place of the gear box and shaft coupling. Accordingly, many different mechanisms may be contemplated by those of ordinary skill in the art that could serve as obvious replacements for the features and components described herein. These obvious variants are intended to fall within the spirit and scope of the present disclosure.

[0043] It should be noted that the term "example" as used herein to describe various embodiments is intended to indicate that such embodiments are possible examples, representations, and/or illustrations of possible embodiments (and such term is not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

[0044] While various embodiments of the disclosure have been shown and described, it is understood that these embodiments are not limited thereto. The embodiments may be changed, modified and further applied by those skilled in the art. Therefore, these embodiments are not limited to the detail shown and described previously, but also include all such changes and modifications.

[0045] Additionally, the format and symbols employed are provided to explain the logical steps of the schematic diagrams and are understood not to limit the scope of the methods illustrated by the diagrams. Although various arrow types and line types may be employed in the schematic diagrams, they are understood not to limit the scope of the corresponding methods. Indeed, some arrows or other connectors may be used to indicate only the logical flow of a method. Additionally, the order in which a particular method occurs may or may not strictly adhere to the order of the corresponding steps shown.

What is claimed is:

1. A vehicle, comprising:

an internal combustion engine;

a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy;

a gear box operatively coupled to an output of the energy conversion system; and

an alternator operatively coupled to the gear box and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

2. The vehicle of claim **1**, wherein the energy conversion system includes a waste heat recovery expander and the output is a shaft of the waste heat recovery expander.

3. The vehicle of claim **2**, further comprising a shaft coupling, wherein the shaft coupling selectively couples to the shaft of the waste heat recovery expander and to a shaft of the alternator.

4. The vehicle of claim **3**, wherein the gear box is structured to substantially match a speed of rotation of the shaft of the waste heat recovery expander to an operating shaft speed for the shaft of the alternator.

5. The vehicle of claim **1**, further comprising an electric power system, the electric power system structured to selectively power the vehicle in at least one of combination with and separate from the engine, wherein the electric power system includes at least one of a variable energy dissipation device, one or more energy storage devices, and an electric motor.

6. The vehicle of claim **5**, wherein the alternator is structured to selectively charge the one or more energy storage devices via the produced electrical energy.

7. The vehicle of claim **1**, wherein the alternator is a part of the front end accessory drive system, wherein the alternator includes a pulley structured to selectively power one or more accessories in the front end accessory drive system.

8. The vehicle of claim **7**, wherein the pulley is coupled to a clutch configured to selectively couple the pulley to the internal combustion engine, wherein the clutch is configured to selectively couple and decouple the pulley from the engine to at least partly control an operating shaft speed of a shaft of the alternator.

9. The vehicle of claim **8**, wherein the clutch is configured to control the operating shaft speed of the shaft of the alternator to substantially match a rotational speed for a shaft of a waste haste recovery expander included in the energy conversion system.

10. The vehicle of claim **7**, wherein the one or more accessories include a power steering pump, an air conditioning compressor, and a water pump.

11. A system, comprising:

an internal combustion engine;

a waste heat recovery system having a working fluid circuit, a fluid management system positioned along the working fluid circuit that utilizes a working fluid, a heat exchange system positioned along the working fluid circuit, and a feedpump positioned along the working fluid circuit and structured to move the working fluid through the working fluid circuit;

an energy conversion system positioned along the working fluid circuit downstream from the heat exchange system and upstream from the fluid management system, wherein the energy conversion system is structured to generate power from heat energy extracted from the engine via the waste heat recovery system;

a gear box operatively coupled to an output of the energy conversion system;

a coupling structured to selectively receive the output of the energy conversion system; and

an alternator operatively coupled to the coupling and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

12. The system of claim **11**, wherein the energy conversion system includes a waste heat recovery expander and the output is a shaft of the waste heat recovery expander.

13. The system of claim **12**, wherein the coupling is structured as a shaft coupling, wherein the shaft coupling selectively couples to the shaft of the waste heat recovery expander and a shaft of the alternator.

14. The system of claim **13**, wherein the gear box is structured to substantially match a speed of rotation of the shaft of the expander to an operating shaft speed for the shaft of the alternator.

15. The system of claim **13**, wherein the alternator is configured to substantially match a speed of rotation for the shaft of the alternator to a rotational speed of the shaft of the expander.

16. The system of claim **11**, further comprising an electric power system, the electric power system operable either with or separate from the engine, wherein the electric power system includes one or more energy storage devices and an electric motor.

17. The system of claim **16**, wherein the alternator is structured to selectively charge the one or more energy storage devices via the produced electrical energy.

18. The system of claim **11**, further comprising an exhaust gas recirculation (EGR) circuit, wherein the heat exchange system further includes an EGR boiler/superheater and a recuperator.

19. The system of claim **18**, wherein the fluid management system includes a condenser, a receiver, and a subcooler.

20. The system of claim **19**, wherein the fluid management system includes a valve module, wherein the valve module selectively facilitates provision of the working fluid to four flow paths in the waste heat recovery system.

21. A method, comprising:

providing an internal combustion engine;

providing a waste heat recovery system in fluid communication with the internal combustion engine, the waste heat recovery system including an energy conversion system, wherein the waste heat recovery system is structured to extract heat energy from the engine, and wherein the energy conversion system is structured to generate power from the extracted heat energy; and

providing an alternator operatively coupled to the energy conversion system and the internal combustion engine, wherein the alternator consumes a first portion of the generated power to produce electrical energy while a remaining portion of the generated power is absorbed by the internal combustion engine via a front end accessory drive system.

22. The method of claim **21**, further comprising providing a gear box and a coupling, wherein the energy conversion system is coupled to the gear box, which is coupled to the coupling, which is coupled to the alternator.

23. The method of claim **21**, wherein the energy conversion system includes a waste heat recovery expander having a shaft, wherein the shaft is received by the gear box.

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